Journal of the Royal Society of Western Australia, Vol. 69, Part 3, 1987, p. 95-112.

Wetlands of the Darling System—A geomorphic approach to habitat classification

by C. A. Semeniuk

21 Glenmere Road, Warwick, W.A. 6024

Manuscript received 17 June 1986; accepted 18 November 1986

Abstract

A classification utilising the 2 primary components of wetlands, the "wetness" and "landform" components, is proposed here. The water component distinguishes wetlands from other terrestrial habitats and also influences biological response by its presence, permanence or longevity, depth, chemistry, and movement. The landform determines wetland size, shape and depth. Using subdivisions of cross-sectional landform geometry there are recognised: basins, channels, and flats. Within the category of water longevity, there are recognised: permanent inundation, seasonal inundation, and seasonal waterlogging. Combining these "wetness" and landform attributes provides 7 categories of common wetlands: 1. permanently inundated basin = *lake;* 2. seasonally inundated basin = *sumpland;* 3. seasonally waterlogged basin = *dampland;* 4. permanently inundated channel = *river;* 5. seasonally inundated channel = *creek;* 6. seasonally inundated flat = *floodplain;* and 7. seasonally waterlogged flat = *palusplain.* Water and landform descriptors/modifiers are used to further augment the nomenclature of the primary units. Modifiers for water include salinity and its consistency. Modifiers for landform include size and shape. Since there are only seven primary wetland types, the classification provides a practicable number of categories for mapping. The addition of more precise or detailed information as modifiers/descriptors increases the ability to discriminate individual wetlands from each other.

Introduction

This paper presents a geomorphic classification of wetlands in the Darling System (Swan Coastal Plain and Darling Plateau; Fig. 1), an area occurring in the subhumid and humid region of southwestern Australia and encompassing coastal plains and dissected plateau. Many classifications of wetlands to date in Western Australia and elsewhere have been based on vegetation and water quality but it is considered that a geomorphic classification best provides the *initial framework* to understanding the various types of wetlands, their distribution and their relationship to biota. The rationale of the geomorphic approach is that ultimately wetlands are related fundamentally to landform development and water maintenance.

The classification presented here may be used for recognising the varied wetland types that occur in the Darling System. Information such as this is needed to establish a geographic, stratigraphic, hydrological and biological pattern in the distribution of wetland types, to determine regional and local significance of wetlands, to determine conservation strategies,and to manage wetlands.

It has long been recognised that wetlands range from: permanent lakes, small to large seasonal lakes, small to large areas of seasonally water-logged soils, fluviatile systems, estuarine systems, and marine systems, and that these categories can be intergradational. Figure 2 illustrates the intergradational relationship between, and attributes of, the various wetland systems, recognising that there are land-based, marine-based and intermediate (estuarine) categories. This paper deals with the land-based wetlands. Estuarine systems and marine systems will be the subject of a later study. The approach of this paper is to provide a review of international literature on wetland classification and nomenclature followed by a review of local studies that deal with wetlands of the Darling System. This is in turn followed by a description of the classification adopted here.

Review of international literature on classification and terms for land-based wetlands

Definition of wetland

In the more recent literature the definition of wetlands encompasses lakes, water-saturated basins, estuaries and fluvial systems (UNESCO 1971, Bayly and Williams 1973, Cowardin *et al.* 1979, Department of Conservation and Environment 1980, Adam *et al.* 1985). However in the older literature the concept of wetland was more rigidly confined to encompass only lakes and water-saturated basins.

A variety of wetland definitions from the international literature is presented here to indicate the wide range of concepts of what constitutes a wetland. The Ramsar Convention defined wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6m" (UNESCO 1971). Zoltai and Pollet (1983) define wetlands as areas where wet soils are prevalent, having a water table near or above the mineral soil for most of the thawed season, supporting a hydrophilic vegetation, and pools of open water (<2m deep). This includes shallow open water. It does not include areas that become temporarily flooded, but remain relatively well drained for most of the growing season. Hill (1978) identifies

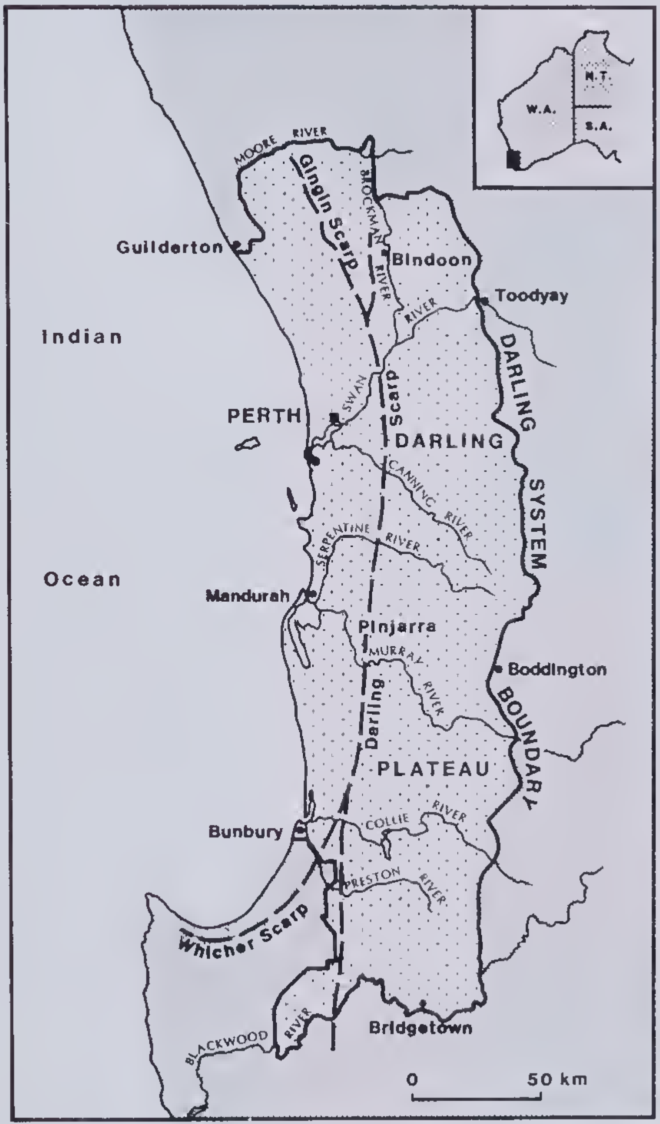


Figure 1.—Location of the study area, the System Six Region in southwestern Australia.

wetlands by the presence of vegetation typically adapted to life in areas inundated or saturated by water with the appropriate duration and frequency to promote that vegetation. Cowardin *et al.* (1979) define wetlands as lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. Cowardin *et al.* (1979) define wetlands as having one or more of the following attributes: 1) at least periodically the land supports hydrophytes, 2) the substrate is predominantly undrained hydric soil 3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year. Bates and Jackson (1980) define wetland as a general term for a group of wet habitats and include areas that are permanently wet and/or intermittently water covered, such as coastal marshes, tidal swamps and flats, and associated pools, sloughs and bayous.

A consensus of Western Australian workers define wetlands as:

> "Areas of seasonally, intermittently or permanently waterlogged soils or inundated land, whether natural or otherwise, fresh or saline, e.g. waterlogged soils, ponds, billabongs, lakes, swamps, tidal flats, estuaries, rivers and their tributaries" (Wetlands Advisory Committee 1977).

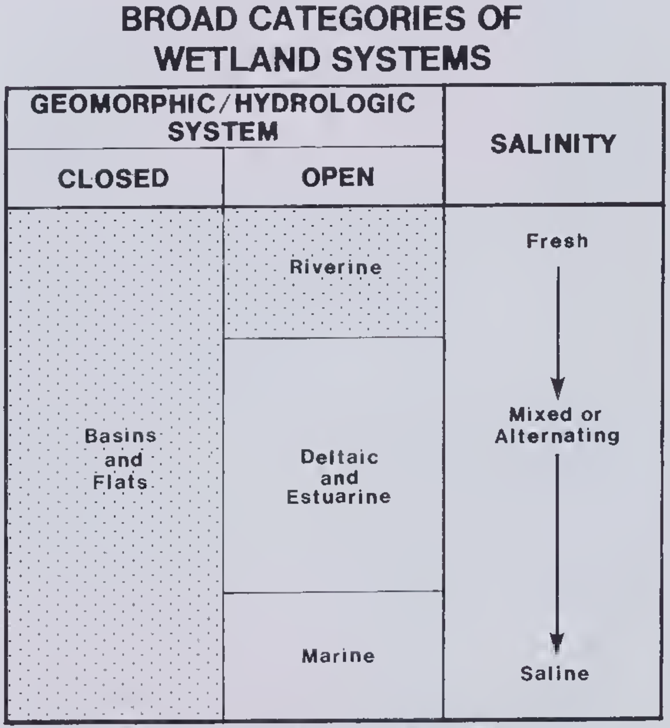
The definition is adequately encompassing and is adopted herein.

Wetland classifications

Wetlands have been examined and/or classified from a number of disciplines: biologically (e.g. mires, swamps; Ivanov 1981, Gore 1983): physically (e.g. riverine lakes, glacial lakes, tectonic lakes; Hutchinson 1957); biologically/chemically (e.g. fens, bogs; Tansley 1939, Gorham 1957, Reeves 1968, Moore and Bellamy 1974, Ruttner 1975, Gore 1983); chemically (e.g. minerotrophic, ombrotrophic etc.; Kulczynski, 1949; Hakanson and Jansson 1980, Wetzel 1983); ontogenetically; and others. It is not proposed to present a historical review of all the terms nor is it intended to explore the meanings of terms which are not widely used. Rather this review documents current terminology, discusses the relevance of those terms to the present classification, and assesses their applicability to the wetlands in the Darling System.

Terms for types of wetlands

Currently inland water bodies can be separated into 4 types: rivers, lakes, mirelands and marshlands. Rivers refer to channelled surface water. Lakes, mirelands, and marshlands are "basin-like" or flat wetlands which are differentiated on the basis of plant colonisation. The recent distinction between running water (Lotic environment) and standing water (Lentic environments) basically identifies the broader categories of riverine



Stippled area marks the categories of land-based wetlands that are the subject of this paper

Figure 2.—Conceptual summary of types of broad wetland categories and their inter-relationships in terms of geomorphic/hydrologic setting and their salinity.

versus "basin-type" of wetlands. The fluvial systems (encompassing rivers, streams, creeks and all other forms of established surface water flow) generally in the past were not considered to be wetlands. Since the documentation and analysis of fluvial systems have been separated traditionally from that of other types of wet habitats, the approaches to their classification have been variable (Schumm 1977, Leopold *et al.* 1964, Twidale 1968, Fairbridge 1968, Bloom 1978).

Fluvial wetland systems

Fluvial systems already have been described and categorised according to geomorphic principles (Gilluly and Waters 1951, Schumm 1977, Leopold *et al.* 1964, Chorley 1969, Bloom 1978, Strahler 1978, Cant 1982, Leeder 1982). Both land and water criteria have been combined to identify and nominate the features of a fluvial system. The recognised geomorphic features of fluvial systems include channels, flood basins and floodplains, levees, crevasses, swamps, and ox-bow lakes (op cit).

Fluvial channel patterns have been subdivided by workers using the criteria of 1) genetic relationship to landform, 2) channel size and position in relationship to branching pattern, 3) sinuosity, 4) water permanence and 5) sediment load. The genetic classification used terms such as subsequent, consequent, obsequent and insequent, and the terms "first order stream", "second order stream", etc were used to categorise relationship of channel to branching pattern. Several classes of channel are recognised on the basis of sinuosity (i.e. the ratio of channel length to valley length); these include straight, transitional, regular, irregular, tortuous, sinuous, meandering, straight-and-braided, and anastomosing (Schumm 1977, Leopold *et al.* 1964, Miall 1977, Cant 1982, Smith 1983); some of these terms are synonymous. Channels occupied by water for different periods of time are referred to as permanent, intermittent, and ephemeral. Predominant sediment transport mode also has been used to classify channels (Schumm 1977) resulting in a similar set of classes as those derived from sinuosity criteria, but with the additional information on channel stability i.e. whether the channel is stable, eroding, or depositional.

Basin wetland systems and flats

Research into "basin-type" inland water bodies or wetlands, has been largely concentrated in the areas of the Temperate, Boreal and Arctic zones of the Northern Hemisphere, particularly Europe, where precipitation is greater than evaporation and/or drainage. The wetlands of these regions are permanently inundated or waterlogged areas and the terms derived from these areas tend to describe only this limited range of wetlands. Examples of wetland terms from these regions are (Gore 1983): lake and mireland (English), moor, see (German), myr (Swedish), suo (Finnish), boloto (Russian), veen (Dutch), myri (Icelandic) and muskeg (Canadian).

Basins were divided, on the presence or absence of emergent vegetation, into 2 water depth types, i.e. those deeper than 2m and those shallower than 2m. The current terms used to distinguish these types are *lake* and *mireland*. Lake has been defined as an "inland body of standing water occupying a depression in the earth's surface, generally of appreciable size (larger than a pond) and too deep to permit vegetation (excluding subaqueous vegetation) to take root completely across the expanse of water; the water may be fresh or saline" (Bates and Jackson 1980). Mireland refers to any area which remains waterlogged and is vegetated (Ivanov 1981).

Lakes have been classified for specific purposes, according to dissolved mineral content, or thermal properties, but the most widely used classification is according to origin (Hutchinson 1957, Reeves 1968, Hakanson 1980, and Jansson 1983, Wetzel 1983). Thus tectonic, glacial, volcanic, solution lakes etc., have been distinguished.

Mirelands have been subdivided into mires and swamps. Mires are permanently waterlogged areas which must include a minimum thickness of peat (Gorham 1957, Moore and Bellamy 1974, Ivanov 1981). They are further divided into two types: bog and fen. A bog is domed, raised above the level of the surface of the surrounding terrain, often with a steep marginal bank (rand). Bogs are oligotrophic, because they rely on atmospheric precipitation, and as a result support a typical vegetation of *Sphagnum* mosses. A fen occurs in hollows or depressions, is minerotrophic and as a result supports a variety of vegetation including mosses, graminoids, or trees. Swamps are permanently waterlogged seasonally inundated, or permanently inundated, vegetated areas. Swamps have alternatively been identified or defined as peat-forming, and non-peat forming (Holmes 1944, Golet and Larson 1974, Ivanov 1981). Swamps are subdivided into numerous different types according to the physiognomy of plant cover (Hofstetter 1983, Anderson 1983, Gore 1983, Denny 1985, and others), e.g. conifer swamps, hardwood swamps, reed swamps, and Ti-tree swamps.

Wetlands other than mirelands, lakes and rivers, are fewer in number in the Northern European climatic zones, but they exhibit enough common similarities in terms of biotic and water parameters to be classified collectively as *marshlands*. Marshlands have been defined as seasonally inundated or waterlogged, with or without a well developed peat, and supporting a graminoid or herb plant cover (Gorham 1953, Riggert 1964-1966, Zoltai and Pollet 1983, Golet and Larson 1974, Campbell 1983, Hofstetter 1983, Denny 1985). The term has also been applied to vegetated peripheral flats of estuaries. Marshlands may be "basin-like" or flats. The types of marshlands are: 1) marshes, 2) swamps, 3) meadows, and 4) wetlands. The range and inconsistency in terms have been brought about by the variability in marshlands occurring outside Europe. Authors describing areas which satisfy only part of the marshland definition (e.g. the seasonal waterlogging of soils) but have different vegetation structure, often use an alternative term or a modifying term to avoid confusion.

Marshes are subdivided on basis of saline and fresh water, geographical distribution (e.g. coastal and inland), and water depth during the growing season (Martin *et al.* 1953, Golet and Larson 1974). The term swamp, used in the sense of, and as a synonym of marsh (Zoltai 1983, Junk 1983, Hofstetter 1983, Howard-Williams and Gaudet 1985) as distinct from a subdivision of mireland is defined as an area intermittently or permanently covered with water, supporting woody plants and essentially lacking peat development. In fact, marsh, swamp, and wetland are sometimes used interchangeably and the general term wetland has been used to describe all land/water interfaces.

General classifications

A variety of classifications have been produced by a number of workers. Some have been comprehensive and generally exhaustive (Cowardin *et al.* 1979) whereas some have concentrated mainly on limnologic wetlands or some specialised aspect of wetlands (Martin *et al.* 1953, Hutchinson 1957, Bayly and Williams 1973, Ivanov 1981, Wetzel 1983, Ruttner 1963). Two of these classifications are outlined below.

Martin *et al.* (1953) produced a classification of wetlands based on 1) geographical position 2) water quality 3) period of flooding 4) depth of water during the growing season and 5) vegetation type within the wetland. The freshwater wetlands were then divided into meadows, marshes, swamps, open water and flats, and were differentiated on the criteria of water depth and/or vegetation cover. Similar wetland categories were proposed for inland and coastal areas and again for saline wetlands. An example from Martin *et al.* (1953) is as follows: "Fresh Inland Meadow: No standing water, but saturated within a decimeter of the soil surface. Shallow depressions. Communities dominated by graminoids and herbs". Within the classification by Martin *et al.* (1953), however, criteria were not applied consistently. In the case of "wooded swamps" the period of flooding is omitted whereas in the categories of "salt flat", "salt meadow" and "irregularly flooded salt marshes", it becomes the distinguishing factor. The use of salinity is another problem with the classification. Salinity was noted to be either fresh or saline. There is no class of wetland which is gradational or dynamic. The cross sectional shape of the wetlands was not differentiated in each class. The terminology does not allow for wetlands with variegated vegetation pattern. Also, the water levels are too specific and in cases, where this is the only differentiating factor, it is too precise for use in Australia.

The classification by Cowardin *et al.* (1979) is a hierarchial one based on recognition of classes, orders and progressively lower levels of taxonomic differentiation. The classification at the onset denotes 5 systems of wetlands that "have certain homogeneous natural attributes"; these are the marine, estuarine, riverine, lacustrine and palustrine systems. Each system is composed of subsystems of littoral and limnetic habitats. The systems are divided into classes and then dominance types, and finally modifying terms are added. The class to which a wetland belongs is determined by the dominant life form of the vegetation (or in the absence of vegetation, the attributes of the substrate); the dominance type refers to the dominant plant or animal species present; the modifiers refer to soil and water attributes of the wetland. The classification was designed so that it could be applied at all levels of data collection. As the information on a wetland increases, the classification may be refined so that two objectives were satisfied: the wetland could be classified immediately within a regional framework, and secondly the wetland could be finally described and differentiated on important individual characteristics.

A number of classifications for wetlands also have been devised by workers in Australia. These classifications are intended mainly for local use (Goodrick 1970, Cowling 1977, Jacobs 1983). Many generally appear to utilize existing overseas schemes and amend them where appropriate for the local system (e.g. Riggert 1964-66, see later). More recently Paijmans *et al.* (1985) provided an overview of Australian wetlands and proposed 6 categories of wetlands (lakes, swamps, land subject to inundation, channels, tidal flats and coastal water bodies). Their approach however is too broad for this study and their categories are based on a variety of mixed criteria.

Application of international classifications to the Darling System

Wetlands of the Darling System are quite variable in shape, size, vegetation, soil, peat, water quality and water maintenance. Wetlands with permanently or seasonally inundated soils have been predominantly described in the literature, but those with seasonally, waterlogged soils generally have been neglected. According to the current international literature most of the wetlands of the Darling System would fall into the categories of 1) channels, 2) lakes, 3) mirelands (fens and swamps) and 4) marshlands. There are no bogs as found in Northern Europe. Marshlands, however, are the most dominant but there are types of marshlands which do not conform to the definition presented above e.g. there are open bodies of water which are fringed by a range of vegetation types, and there are areas of seasonally waterlogged soils supporting variable vegetation.

Use of riverine terms

The genetic and quantitative classifications for rivers and streams (Twidale 1968, Fairbridge 1968) are considered inappropriate for channels of the Darling System because they do not provide precise information on the important features of shape, size and permanence, factors that are considered to be important in the identification of the wetland habitat. The terms of these classifications furthermore have neither ecological nor descriptive geomorphic implication. The classification involving sediment load relates to stream function and also does not convey the necessary descriptive information useful to identify the various channel wetlands. The terms used to describe sinuosity are appropriate to describe wetland channels because they convey geometric impressions of the channel system particularly if used in conjunction with size terms. However it is necessary only to use a limited range of these terms to convey channel sinuosity; these are: straight, anastomosing, irregular and sinuous.

Use of vegetation in classification

Vegetation (using features of floristics or structure, or both) has been used to classify wetlands (Martin *et al.* 1953, Goodrick 1970, Cowardin *et al.* 1979, Briggs 1981, Campbell 1983, Sjors 1983, Pisano 1983, and others). In some cases vegetation has even been used to unravell the edaphic features of wetlands. For instance, Ivanov (1981) deduces hydrology, stratigraphy, origin and development from the use of restricted plant habitats in mire ecology and uses species presence and structure in relation to micro-relief to determine the structure of mire formations. Vegetation has been used to differentiate types of mires and swamps (e.g. spruce swamp, pine bog).

It is considered here, however, that vegetation should not be used as a primary criterion to classify wetlands of the Darling System. The vegetation structure is dependent upon hydrological and geomorphological factors such as water maintenance, water quality, micro-relief and soils, so that the primary classification of wetlands solely based on vegetation structure may not allow any differentiation of other wetland properties. Also, because of the relatively limited species pool that dominantly contribute to the vegetation of wetlands, the use of vegetation as a primary criterion would result in many different wetlands being classified into one group. Consider for example paperbark forests and woodlands which occur on deltas, along river banks, on flood plains, along the edge of basins, in blow outs, in interdune depressions and fringing the shores of estuaries; the use of this vegetation in classification would not bring out the various and different primary wetland categories.

Use of water quality in classification

Wetlands have been subdivided variably on the basis of different water types, such as ombrotrophic and minerotrophic, or aspects of salinity (Tansley 1939, Martin *et al.* 1953, Bayly and Williams 1973, Moore and Bellamy 1974, Gore 1983) and in some cases it forms the primary criterion for classification. More usually the subdivision of water categories merely provides a secondary subdivision of wetland types.

Since most of the wetlands in the Darling System are maintained by groundwater, it must be concluded that they are to some extent minerotrophic. However, the input of rain during the wet season shifts wetlands to the ombrotrophic end of the spectrum. Although this simple division based on dissolved mineral content cannot be used successfully, the division according to salinity or to the presence of one or more minerals may be attempted. The use of water quality is considered important at lower hierarchial levels but not at a primary level. Accordingly salinity terms such as freshwater, brackish water, subsaline, hyposaline, saline water and hypersaline water become applicable (Davis and DeWiest 1966, Logan *et al.* 1974, Cowardin *et al.* 1979, Dreva 1982, Hammer *et al.* 1983). An excellent review of the problems of terminology of categories of water quality is provided by Hammer (1986). The consistency of water quality also is considered here to be relevant in classification at lower hierarchial levels, because of the seasonal variation in water quality of many wetlands of the Darling System.

Use of peat/stratigraphy in classification

The secondary classification of mirelands into fens and bogs is based on the presence/absence of peat and essentially underscores botanical and shallow stratigraphic aspects of wetlands. Taken to conclusion the stratigraphic approach would result in wetlands being categorised on the origin of their surficial soils such as peat, carbonate mud, diatomite, gypsum deposits, etc. Wetland shallow stratigraphy in the Darling System is primarily determined by the vegetation type, the geomorphic unit in which the wetland is situated, and the developmental history of the wetland. This shallow stratigraphy is often complex and necessitates detailed analysis. Thus although it is very important in understanding wetland formation, stratigraphic information is considered to be inappropriate at the higher hierarchial levels of classification.

An additional complication relates to the age of peat units. Peat and peaty sand occur in many of the wetlands in the Darling System and are forming under present conditions; they are young and often less than a metre thick. In some places, however peat has been buried to some depth and is essentially a "fossil" deposit. The buried peat horizons may be relics of a different climatic or wetland regime and should form no part of a classification dealing with modern processes.

Use of internal morphology in classification

Morphological criteria such as internal relative relief is used by a number of authors for basin wetlands (Moore and Bellamy 1974, Ivanov 1981, Gore 1983) but its use has tended to be subtly introduced at all stages of classification. Where not directly mentioned, the wetland internal morphology often is implied in the use of vegetation structure and the water quality. For instance with bogs and fens, use is made of vegetation structure to infer the varieties of depressions, hollows, basins, flats or slopes. In essence the use of internal morphology in the international literature is merely a variation of the use of vegetation criteria.

Use of external morphology in classification

The morphology of fluvial systems has been successfully classified by a number of authors and according to these approaches fluvial wetlands of the Darling System could be classified as to channel shape and water permanence. The external shape of basin-wetland landform, however, generally is not directly considered in the international literature even though it is one underlying factor for the presence and extent of the wetland itself and therefore should be a primary factor in the classification of wetlands. In the Darling System the morphological components of the landforms produce definite, recognisable types of wetlands, and small scale sedimentological features of wetlands can also be used for more detailed categorisation. The larger morphological components are considered to be crucial in the primary classification of wetlands from a geomorphic viewpoint as will be discussed later in the paper.

Discussion

The review of international literature shows that classifications and nomenclature of wetlands have been based on amost every edaphic or ecological aspect of the system: water supply, water chemistry, type of landform, morphological structures within the wetland, shape of wetlands, vegetation cover, and occurrence/types of peat. There have been integrated approaches such as the genetico-geotopic classification of Ivanov (1981), the wetland classes of Zoltai *et al.* (1983), and the five major systems of Cowardin *et al.* (1979). There also have been numerous classifications based on a single feature, the most common being vegetation.

The primary classification of wetlands into lake, mireland and marshland is inconsistently based on the duration and depth of water supply and shows no clear demarcation between wetlands with different water levels and longevity. Three types of water longevity are explicitly recognised by authors: 1) permanent inundation, 2) permanent waterlogging, 3) seasonal inundation or waterlogging, but the terms lake, mireland and marshland clearly do not mirror these categories; for example:

- Permanently inundated areas may be termed lake or swamp
- Permanently waterlogged areas may be termed mire, swamp, marsh

- Seasonally inundated or waterlogged areas are termed wetland, marsh, meadow, swamp.

There is no term other than marsh to refer to seasonally waterlogged areas, as opposed to seasonally inundated surfaces.

It is also clear that most classifications of wetland rely heavily on categorisation using vegetation (which is presumed to reflect water longevity and quality) at a primary or secondary level. The classification of wetlands where landform is linked to water permanence/longevity generally is not an approach adopted in the literature. For instance, wetlands divided into lake or mireland then are subdivided according to biotopes (i.e. the presence or absence of peat and, on the physiognomy of the plant cover). The third major factor in categorising wetlands appears to be the use of water quality. This may be based simply on aspects such as minerotrophism, or specific salt content, or acidity.

Further subdivisions or classifications of wetlands have been based on the genetic morphologic relationships of the entire wetland systems at a regional scale, or on vegetation-related internal morphological components of the wetland and the resulting structure of the vegetation, or the presence of specific vegetation (Moore and Bellamy 1974, Cowardin *et al*, 1979, Ivanov 1981, Gore 1983, Ruuhijarvi 1983, Sjors 1983).

The terms available in the literature that are useful in classifying wetlands at a primary level therefore are:

the term *wetland* itself,
the term *lake*,
riverine geomorphic nomenclature such as river, creek, channel sinuosity terms, etc.

A wide variety of wetland categories or terms therefore are considered inapplicable for the Darling System because they are genetic, or they have imprecise definition, or have strong vegetation connotation, or soil/stratigraphy connotation, or they should be at lower stage levels of hierarchy in classification, or because they do not fully extend across the range of wetlands available in the Darling Systems; these are:

1. *genetic chemical categories* such as ombrotrophic, minerotrophic etc.;
2. *morphogenetic categories* such as volcanic lake, glacial lakes;
3. *floristic categories* such as swamp, meadow, marsh, muskeg;
4. *chemical-floristic* or *soil-floristic* categories such as mire, swamp, moor, fen, bog etc.;
5. *geologic/geographic* base categories such as paludal, continental;
6. the terms lake, swamp, marsh as used in a *sedimentologic* sense.

Previous local classification of wetlands

There have been previous classifications of the wetlands of the Swan Coastal Plain and Darling Plateau of the Darling System, notably by Serventy, Owen and Pirrott (cited by Clarke *et al*. 1971), Riggert (1964-1966), Tingay and Tingay (1976) the Wetlands Advisory Committee (1977), and Allen (1980). All these classifications devised to date have useful purposes since each was developed for a specific task. These systems of classification are briefly discussed below.

Classification adopted by Serventy, Owen and Pirrott

Serventy *et al*. (1971) (cited by Clarke *et al*. 1971) in an unpublished document probably provided the first classification of wetlands in the Darling System. Three genetic types of lakes or swamps were distinguished: 1) isolated portions of the ocean; they cited examples such as Preston-Clifton Lakes; 2) relic abandoned river courses of which Herdsman and Perry Lakes are cited as examples and 3) chance depressions.

Classification adopted by Riggert

As part of a study into wetlands of Western Australia by the Department of Fisheries & Fauna, Riggert (1964-1966) classified and evaluated wetlands of Western Australia (including the Darling System) (see Fig 1). The study was oriented to evaluating the utilisation of wetlands by waterfowl. Riggert postulated that the presence or absence of waterfowl provided an indication of the physical state of a wetland. The wetlands were classified on criteria developed by Martin *et al*. (1953) into 22 types. These were A. *INLAND FRESH AREAS* 1. Seasonally flooded basins or flats 2. Flooded Agricultural Land 3. Inland fresh meadows 4. Inland shallow fresh marshes 5. Inland deep fresh marshes 6. Inland open fresh water 7. Permanent Open Water (Reservoirs) 8. Shrub swamps 9. Wooded swamps and 10. Bogs; B. *INLAND SALINE AREAS* 11. Inland saline flats 12. Inland saline marshes and 13. Inland open saline water; C. *COASTAL FRESH AREAS* 14. Coastal shallow fresh marshes 15. Coastal deep fresh marshes amd 16. Coastal open fresh water; and D. *COASTAL SALINE AREAS* 17. Coastal salt flats 18. Coastal salt meadows 19. Irregularly flooded salt marshes 20. Regularly flooded salt marshes 21. Sounds and bays 22. Mangrove Swamps.

Examples of these categories of wetlands in Western Australia were described in an inventory approach by Riggert noting size, depth, total surface area and vegetation. The wetlands were also categorised and evaluated on the basis of utilisation by waterfowl, in terms of numbers of waterfowl per year, and types of utilisation (e.g. breeding, feeding, migration and loafing).

The approach by Riggert (1964-1966) indicated that there was much variability in wetland types. However, it did not distinguish between the many types of wetlands that exist in the Darling System that can be separated on the basis of geometry, vegetation, degree of water permanence and other faunal groups apart from avifauna. For instance, riverine wetlands were not distinguished.

Classification adopted by Tingay and Tingay

As part of a study into wetlands of the Darling System prepared for the Environmental Protection Authority, Tingay and Tingay (1976) classified and compiled an inventory of wetlands in the southwest of Western Australia. They adopted the classification of Hutchinson (1957) and Bayly and Williams (1973), wherein wetlands in the first instance are classified into lentic and lotic. Tingay and Tingay (1976) utilised schemes that subdivided the lentic categories into 1) lakes: tectonic, volcanic, landslide, glacial, solution, fluviatile, wind action or coastal types, and 2) shallow water bodies: underground water, springs, water associated with terrestrial vegetation, puddles, rock pools and ponds, either permanent or temporary. Lotic categories were sub-divided as permanent, temporary or episodic, and also on features such as unidirectional flow, fluctuation in flow rates, linear morphology, etc.

Tingay and Tingay applied the classification to the Darling System and noted that *lentic* wetlands dominate the Bassendean, Quindalup, Spearwood and Pinjarra geomorphic systems of McArthur and Bettenay (1960), and that each wetland type within a geomorphic system may have similarity in terms of origin, nature and biota. Tingay and Tingay classified the lakes at Yanchep for instance, as lentic solution lakes, and the wetlands of the Bassendean system as lentic wind action dune water table lakes. They further subdivided the lentic wetlands of the coastal plain on the basis of soil elements and series (i.e. they adopted soil associations as environmental indicators) and they devised an acronym symbol system to distinguish them. The lotic wetlands were subdivided by Tingay and Tingay on a geographic basis into Moore, Swan, Peel, Leschenault, Capel and Hardy types with no further subdivision.

The approach of Tingay and Tingay (1976) constituted a useful categorisation of wetlands for inventory purposes. The categories provided a checklist of features to be determined for each wetland and highlighted the variability of wetlands. However, the system adopted is too genetic in the first instance, as well as too complicated both for classification purposes and for mapping. It involves a worker having to determine a wide range of factors such as soil mosaics and landform origin before a classification is possible. Yet a simpler classification is possible based on readily-available features gathered from maps and short field surveys. It should be noted, however, that many of important features of wetlands used by Tingay and Tingay are utilised in the classification developed herein.

Classification adopted by Wetlands Advisory Committee (1977)

The Wetlands Advisory Committee (1977) in a report to the Environmental Protection Authority also devised a classification of wetlands in the Darling System. The main subdivisions adopted by the committee were: 1) Lentic (non-flowing), 2) Lotic (flowing), 3) Estuarine, and 4) Artificial. Thereafter the wetlands were subdivided on criteria of size, salinity, permanence, and degree of vegetation cover. These criteria were considered important to determine the potential value of a wetland for particular uses (e.g. waterfowl drought refuge; or use for aquatic recreation). This approach produced a total of 15 potential types of lentic wetlands, which together with the lotic, estuarine and artificial types identified a total of 18 wetland types throughout the Darling System region.

Wetlands classified by the Wetlands Advisory Committee were allocated symbols (similar to Tingay and Tingay 1976) to distinguish them. Thus Lake Jandabup at Wanneroo was designated LE.f.1.p.sc (lentic, fresh, large, permanent, semi-closed vegetation cover), the Swan River upper reaches were designated LO (lotic); the Swan River at Fremantle was designated E (estuarine) and ornamental lakes in Kings Park were designated A (artificial).

The classification of the Wetlands Advisory Committee (1977) provided a useful categorisation of various types of wetlands. It addressed many of the major attributes of wetlands and clearly showed their variability and complexity in the Darling System. However the classification did not utilise wetland shape, only distinguished between two sizes of wetland (small and large), did not separate types of Lotic systems and did not distinguish between various "basin-type" wetlands or identify wetland flats.

Classification by Allen

As part of a geohydrology study of the Swan Coastal Plain, Allen (1976, 1981) identified wetlands as lakes and swamps and further categorised them into six types on the basis of age, inferred origin, and geographic location. Allen identified the following: 1) Bambun type, 2) Gnangara type, 3) Forrestdale type, 4) Joondalup type, 5) Gwelup type and 6) Cooloongup type. These categories 1-6 were listed in order of inferred decreasing age.

Other studies

In addition to the works cited above in which classification of wetlands was a primary or important motive, there are other works in which some form of wetland classification or wetland vegetation classification was utilised. These works include Evans and Sherlock (1950), McComb and McComb (1967), Seddon (1972), Bell *et al.* (1979), Watson and Bell (1981); Muir (1983), Pen (1983), Speck and Baird (1984), Congdon and McComb (1976) and Baird (1984). Each of these works utilised established international classification schemes. Thus the Yanchep wetland system was termed a swamp and fen formation (McComb and McComb 1967), Star Swamp and Yeal Swamp were termed swamp and swampy flat, respectively (Watson and Bell 1981, Baird 1984), and Seddon (1972) utilised terms such as wetland, swamp, lake.

Discussion

All classifications devised to date have not provided an approach that enables categorisation of the variety of wetlands across the whole Darling System. Only 3 of the classifications have attempted to be comprehensive. These are the works of Riggert (1964-66), Tingay and Tingay (1976), and the Wetland Advisory Committee (1977). However, even the most detailed of these classifications use an essentially similar primary subdivision of lentic and lotic types (Tingay and Tingay 1976, Wetlands Advisory Committee 1977). The distinction between still-standing water and flowing water (which is the basis of the lentic and lotic subdivision and essentially attempts to separate fluvial from lacustrine wetlands) however becomes indefinite in some systems, e.g. some channels are slow flowing, and in fact, have slower flow rates than some lakes, that are part of a groundwater drainage system. The approach to classifying lakes by Tingay and Tingay (1976) is too genetic to be of use and secondly only considers part of the range of wetlands available, since many wetlands may have no free-standing water at any time of year. A classification that separates the wetland into numerous types as proposed by Riggert (1964-1966) serves as a useful function in identifying wetlands for use of avifauna but does not provide the adequate distinction for additional purposes between the many varied wetland types existing in the Darling System.

All the above classifications to date however have not adequately addressed the identification and nomenclature of waterlogged soils, or types of water saturation/inundation or the full range of cross-sectional and plan geometry of wetlands, or the range of sizes of wetlands.

Classification—this study

Philosophical approach to classification

Ideally classifications should initially be non-genetic and then with additional information the non-genetic categories should relate to genetic categories. Landform/geomorphic and water/wetness criteria are non-genetic and the proposed classification of wetlands is based fundamentally on the two major features which determine the existence of wetlands i.e. the water and landform components. The water component is the major feature that distinguishes the wetland habitat from other terrestrial habitats and also the component which influences biological response by its presence, depth, chemistry, and movement. The landform essentially is the "water container" and thus it determines the size, shape and depth of a wetland. Any wetland classification thus should reflect variability or attributes of these two components (Figure 3). In combination, the variables or attributes of these two components result in a wide spectrum of possible wetland types. As a prerequisite to examining these combinations, a fuller explanation of the types of subdivision of water and landform is presented below.

The water component

The component of water in a wetland may be viewed from 4 inter-related aspects: 1) its persistence or longevity, 2) its quality, 3) the consistency of water quality, and 4) the mechanism by which water maintains the wetland.

The longevity of water residing in a wetland, i.e. its permanence or intermittency, is directly related to the precipitation and evaporation, mechanisms of water supply, the permeability of underlying sediments, and the shape of the wetland. Three types of longevity are distinguished: 1) permanent inundation 2) seasonal or intermittent inundation 3) seasonal or intermittent waterlogging (without inundation).

Water quality referring to the dissolved solids, rather than pH or coloration, may be subdivided into categories of: fresh, brackish (or mixosaline), saline and hypersaline. However, there is inconsistent use of terms and definitions for categories such as brackish, saline, hypersaline (Davis and Dewiest 1966, Drever 1982, Cowardin *et al.* 1979, Logan *et al.* 1974, Hammer *et al.* 1983, Hammer 1986). The category terms and boundaries adopted in this paper are presented in Table 1. It also should be pointed out that many wetlands vary in salinity during the year due to variable input of water sources and evapo-transpiration. Wetlands that are seasonally variable in salinity are categorised by the salinity state in which the wetland exists for the major part of each year e.g. a wetland that ranges from freshwater for most of the year, to brackish during the season of reduced water supply, would be classified as freshwater. However, a term is introduced to denote whether salinity is constant or variable. Water quality that is consistent throughout the year (i.e. it remains totally within a given salinity field, e.g. the freshwater field or saline water field) is termed *stasohaline**; water quality that markedly fluctuates throughout the year is termed *poikilohaline**. For instance a wetland that alternates seasonally from freshwater to saline is described herein as poikilohaline. In areas of seasonal inundation and seasonal waterlogging, the determination of salinity throughout the year will necessitate sampling the shallow groundwater for part of the year.

Table 1

Classification of water salinity based on total dissolved solids

Salinity mg/l	Water Category*
less than 1,000	Fresh
1,000—3,000	Subhaline
3,000—20,000	Hyposaline
20,000—50,000	Mesosaline
50,000—100,000	Hypersaline
100,000 and greater	Brine

*The terms and boundaries for fresh, subhaline, hyposaline mesosaline and hypersaline are from Hammer 1986; the term "brine" is delineated by Davis and Dewiest 1966.

The mechanisms by which water maintains the wetland are variable and include direct precipitation, groundwater seepage, surface inflow, ponding etc. However the mechanisms of water maintenance will not be considered further here.

Landform component

The landform component of a wetland can be categorised on the basis of cross sectional geometry, plan geometry and scale. The cross sectional geometry subdivides a wetland into basins, flats and channels. Basins and flats have no external surface drainage system. Basins range from flat bottomed to concave, from steep to gentle sloping sides, from shallow to deep and are represented by many of the common and ubiquitous lakes and "swamps" of the Swan Coastal Plain. They have clearly defined centres or depressions but may have sharp or broad margins. Cross sectional shapes of basins include: broad u-shape, steep u-shape, saucer, and slightly concave depressions. It is on the basis of a topographic depression that an individual basin is recognised. This factor is particularly important when a number of basins may form a nearly coalescing network; the local central depressions define each basin even though the littoral zones of adjacent basins may merge or overlap. Flats are marked by little or no marginal relief, and have diffuse lateral boundaries. Flats in the Darling System commonly occur on the tributary interfluves of creeks and rivers, as overbank floodplains, and on broad alluvial flats and slopes in front of foothills of the Darling Scarp.

Channels refer to any incised water course, or reach, including those connecting basin-type bodies of water. Channels have clearly defined margins and may be bedrock confined or alluvial and this distinction may result in deeply incised channels as opposed to shallowly incised channels. The alluvial channels vary according to their hydraulic characteristics which are determined by their stability, channel and valley slope gradients, the mode of transport, and composition of their load (suspended vs. bedload).

---

*staso ....after Greek Stasimos (=constant)

*poikilo ....after Greek Poikilos (=variable)

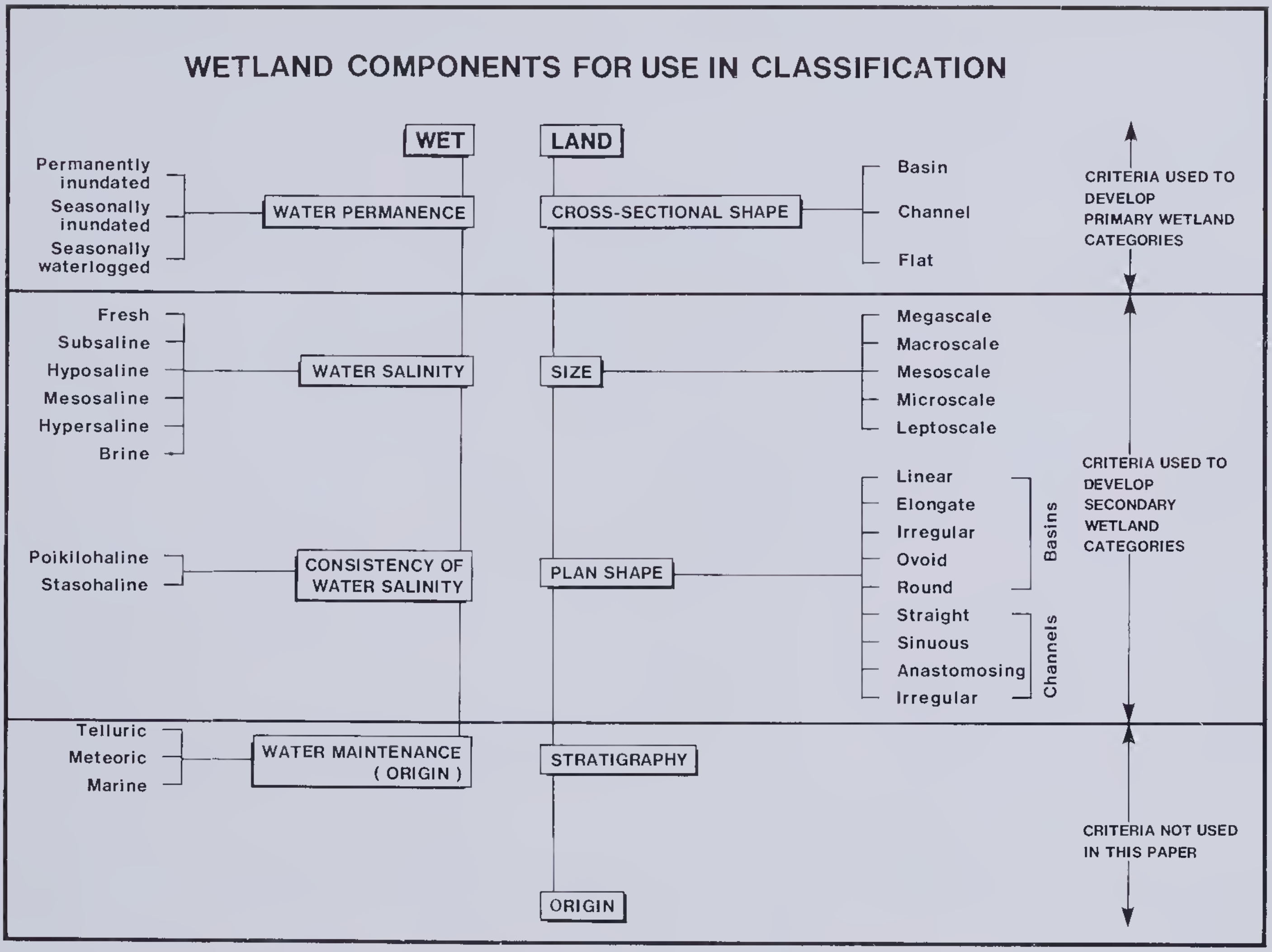


Figure 3.—Components or attributes of wetlands and their terminology used in the proposed classification.

Channel terms include rivers, streams, brooks, creeks, drainage lines or troughs. Only the terms rivers and creeks are used in this classification.

In plan form, encompassing the limnetic and littoral zones (Hutchinson 1957, Cowardin *et al.* 1979), wetland shapes are easily discernible and may be described as linear, elongate, irregular, ovoid or round, for basins; and straight, sinuous, anastomosing, or irregular for channels (Fig. 4).

Wetlands may be further categorised according to scale. For basins and flats the categories of geomorphic scale (modifed from Semeniuk 1986) are:

Megascale: Very large scale wetlands larger than a frame of reference 10km x 10km

Macroscale: Large scale wetlands encompassed by a frame of reference 1000m x 1000m to 10km x 10km

Mesoscale: Medium scale wetlands encompassed by a frame of reference 500m x 500m to 1000m x 1000m

Microscale: Small scale wetlands encompassed by a frame of reference 100m x 100m to 500m x 500m

In the case of channels, a definitive width to length relationship is used:

Macroscale: Large scale channels 1km and greater wide, by several to tens of kilometres long.

Mesoscale: Medium scale channels hundreds of metres wide, by thousands of metres long.

Microscale: Small scale wetlands tens of metres wide, hundreds of metres long.

Leptoscale: Fine scale channels several metres wide, tens of metres long.

The suggested order of importance to classification for the components of landform is presented in Figure 3.

The proposed classification

The classification of wetlands proposed here has been developed by combining the various components of water and landform. Using primary subdivisions of cross-sectional landform geometry there are recognised:

- basins
- channels
- flats

Within the category of basin, using primary subdivision of water there are recognised:

- permanently inundated types
- seasonally inundated types
- seasonally waterlogged types.

Within the category of channels there are:

- permanently inundated types
- seasonally, or intermittently, inundated types.

Within the category of flats there are:

- seasonally, or intermittently, inundated types
- seasonally, or intermittently, waterlogged types.

This categorisation then allows recognition of 7 main wetland types:

Water Longevity	Landform		
	Basin	Channel	Flat
Permanent inundation	Permanently inundated basin	Permanently inundated channel	—
Seasonal (or intermittent) inundation	Seasonally inundated basin	Seasonally inundated channel	Seasonally inundated flat
Seasonal (or intermittent) waterlogging	Seasonally waterlogged basin	—	Seasonally waterlogged flat

These basic 7 categories require nomenclature so that they may form the primary units of wetland differentiation. Permanently inundated flats and seasonally waterlogged channels are not common wetlands.

The proposed terms for the basic wetland units are:

1. Permanently inundated basin =LAKE
2. Seasonally inundated basin =SUMPLAND
3. Seasonally waterlogged basin =DAMPLAND
4. Permanently inundated channel =RIVER
5. Seasonally inundated channel =CREEK
6. Seasonally inundated flat =FLOODPLAIN
7. Seasonally waterlogged flat =PALUSPLAIN

Some of the terms above are established and well defined previously in the literature and hence have been re-utilised. Others (i.e. sumpland, dampland, palusplain) have been coined in this paper. The rationale for, the definition of, and the origin of the terms are described in Table 2. A comparison of the proposed wetland terms with other previously established terms is provided in Table 3. It should be noted that the terms river and creek are used to denote permanence and intermittency of water flow, respectively; the size of the river or creek is indicated by the use of the scale modifier.

Areas such as damplands and palusplains which are rarely or infrequently inundated do not necessarily qualify to be termed sumplands and floodplains. The characteristic of seasonal waterlogging should be a prevailing, recurring feature and this is the deciding factor in determining the categorisation of a wetland by the longevity and type of its "wetness". The occasional or infrequent flooding of terrain can take place anywhere during torrential rainfall or sheet flooding but such phenomena do not categorise the temporarily inundated land surface as a wetland. An example illustrating how a basin cross sectional geometry interacts with a varying water level to develop 3 categories of wetland (i.e. lake, sumpland and dampland) is presented in Figure 5.

Further uses of water and landform descriptors/modifiers are implemented to elaborate and ornament the nomenclature of the primary units. For example, the Swan Coastal Plain contains numerous examples of freshwater large scale ovoid, permanently inundated basins, that remain fresh throughout the year; these would be simply and obviously termed freshwater, stasohaline macroscale, ovoid lakes. Lake Coogee for instance is a hyposaline, stasohaline, macroscale, ovoid lake; Lake Joondalup is a freshwater, stasohaline macroscale lake; Lake Pinjar is a freshwater, stasohaline megascale sumpland.

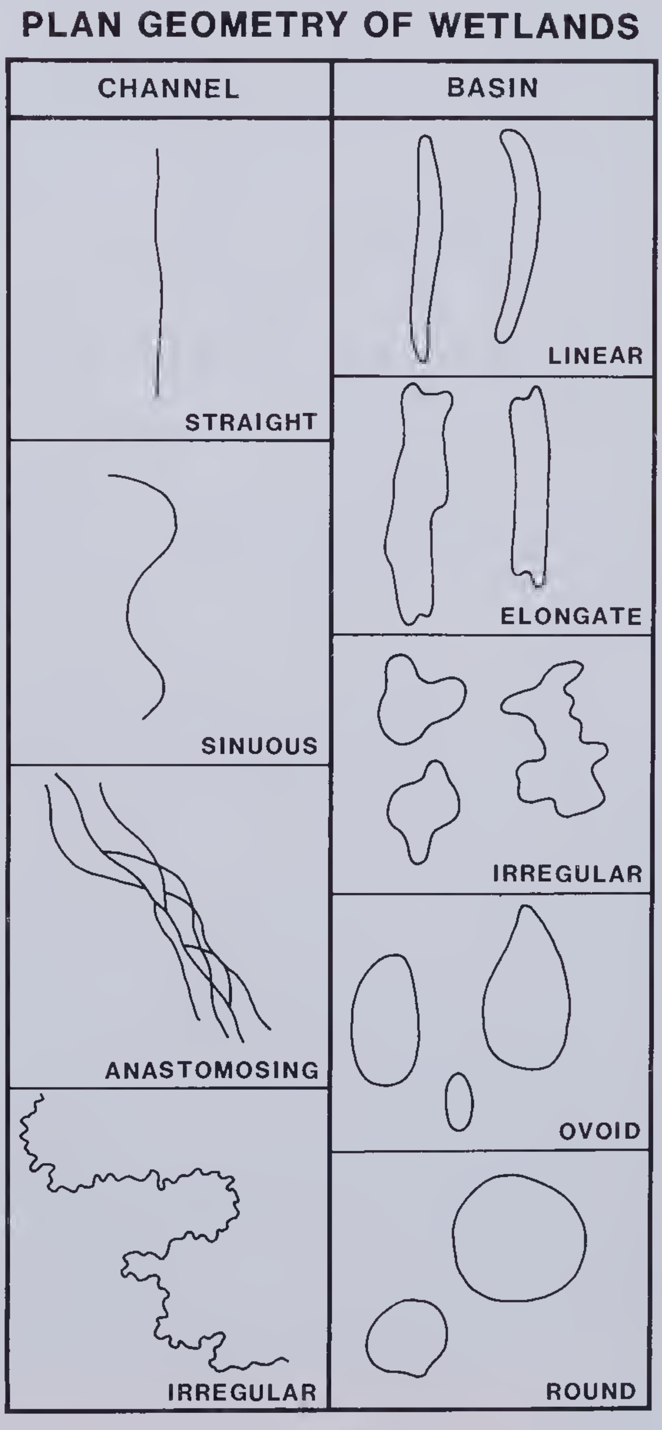


Figure 4.—Plan geometry of basin and channel wetlands.

The full range of descriptors/modifiers are listed in Figure 3. A variety of wetland types developed by various combinations of water and landform features are listed in Table 4 together with some examples of each. Figure 6 illustrates a typical range in geometry and size of various wetlands in the Darling System.

Table 2

Definition and origin of terms

Wetland term	Definition	Defined by	Origin of term	Usage in this paper
Lake	Permanently inundated basin of variable size and shape	Mill (1900-1910) Monkhouse (1965) Bates & Jackson (1980) Fairbridge (1968) Ruttner (1953)	Established term, from Latin *lacus*, a hollow.	The usage in this paper does not distinguish between shallow lakes and deep lakes.
Sumpland	Seasonally inundated basin of variable size and shape	This paper	After "sump" meaning site of water retention or ponding or accumulation; The term is fortuitously similar to "sumpf" the German term for swamp	As defined.
Dampland	Seasonally waterlogged basin of variable size and shape	This paper	After "damp" meaning moist or wet. Thus it refers to a dampness or waterlogging of soils of some basin wetlands	As defined.
River	Permanently inundated channel of variable size and shape	Swayne (1956) Trowbridge (1962) Morisawa (1968)	Established term from Latin of most *rivus*, a stream (Shipley 1982)	This usage conforms with the concept of other authors that a river is defined as channelled water flow, but is different to most authors in its necessity for permanence of water. The permanence of water, also generally implies a channel of large rather than small size.
Creek	Seasonally inundated channel of variable size and shape	Whittow (1984) Monkhouse (1965) Trowbridge (1962) Bates and Jackson (1980)	Established term	This usage generally conforms with that of Australia and southwestern U.S.A.
Floodplain	Seasonally inundated flat	Mill (1900-1910) Monkhouse (1965) Moore (1949)	Established term	This differs from other authors in that inundation of the plain need not be linked to a river; in general however a floodplain is associated with a river or creek.
Palusplain	Seasonally waterlogged flat	This paper	After latin *palus* meaning "marshy"; thus the term refers to flats which are similar to dampland basins.	As defined.
Stasohaline	Water of relatively constant salinity remaining in a given salinity field	This paper	After staso (Greek) meaning constant	As defined.
Poikilohaline	Water of variable salinity fluctuating from one salinity field to another	Originally defined Dahl (1956)	After poikilo (Greek) meaning variable	As defined.
Waterlogged	Area in which water stands near, or at the land surface		Established term	Usage conforms with Golet and Larson (1974), Martin *et al.*, (1953) and most other authors.

The use of vegetation in describing and classifying wetlands has always been accepted by wetland workers. Vegetation has been viewed in previous work in terms of: 1) structure, 2) life form, 3) species dominance, 4) percentage cover of area, and 5) zonation. Each of these parameters significantly increase understanding of an individual wetland, and its uniqueness or similarity to other wetlands. The methods for describing vegetation have been thoroughly documented by numerous authors, as have interrelationships with physical chemical and biological variables. Vegetation also becomes important when correlating or establishing ecological linkage for chains or series of wetlands in the same physiographic settings, but because it is a dynamic, responsive and mutable feature, it is suggested that the use of vegetation should only be employed in a later stage description of individual wetlands as opposed to initial stage regional descriptions of wetlands. It is suggested that the use of vegetation be applied in a tertiary or quaternary modifier capacity. As such, it is suggested that vegetation be used as an adjectival modifier to the wetland classification by utilising floristic and structural terms with a primary wetland class. However it should be pointed out that categorisation/classification of wetland vegetation becomes a difficult task where vegetation is not a simple extensive unit but rather concentrically zoned, or in the form of complex mosaics.

The use by many limnologists and biologists (Hutchinson 1957, Wetzel 1983, Ruttner 1953, Bayly

Table 3

Comparison of wetland terms used in this paper with established classifications

This paper	Martin *et al.* (1953)	Cowardin *et al.* (1979)	Golet & Larson (1974)	Paijmans *et al.* (1985)	General European	General N. American
Lake	Open fresh water Deep fresh marshes Open saline water	Lacustrine	Open water Shrub swamp Deep marsh	Lakes Swamp Coastal water bodies	Lake Swamp	Lake Swamp
Sumpland	Wooded swamp Seasonally flooded Basins Shallow fresh marshes Deep fresh marshes Saline marshes Open saline water	Palustrine	Deep marsh Shallow marsh Shrub swamp Wooded swamp Open water	Lakes Swamp	Marsh	Marsh Meadow
Dampland	Fresh meadows Wooded swamp	Palustrine	Meadow	—	—	Meadow
River	—	Riverine	—	River and creek channels	River Stream Creek Brook	River Stream Creek Brook
Creek	—	Riverine	—	River and creek channels	—	Arroyo
Floodplain	Shrub swamp Wooded swamp	—	Seasonally flooded flats	Land subject to inundation	Floodplain	Floodplain Seasonally Flooded flat
Palusplain	Wooded swamp Saline flat Salt meadow?	Palustrine	—	—	—	—

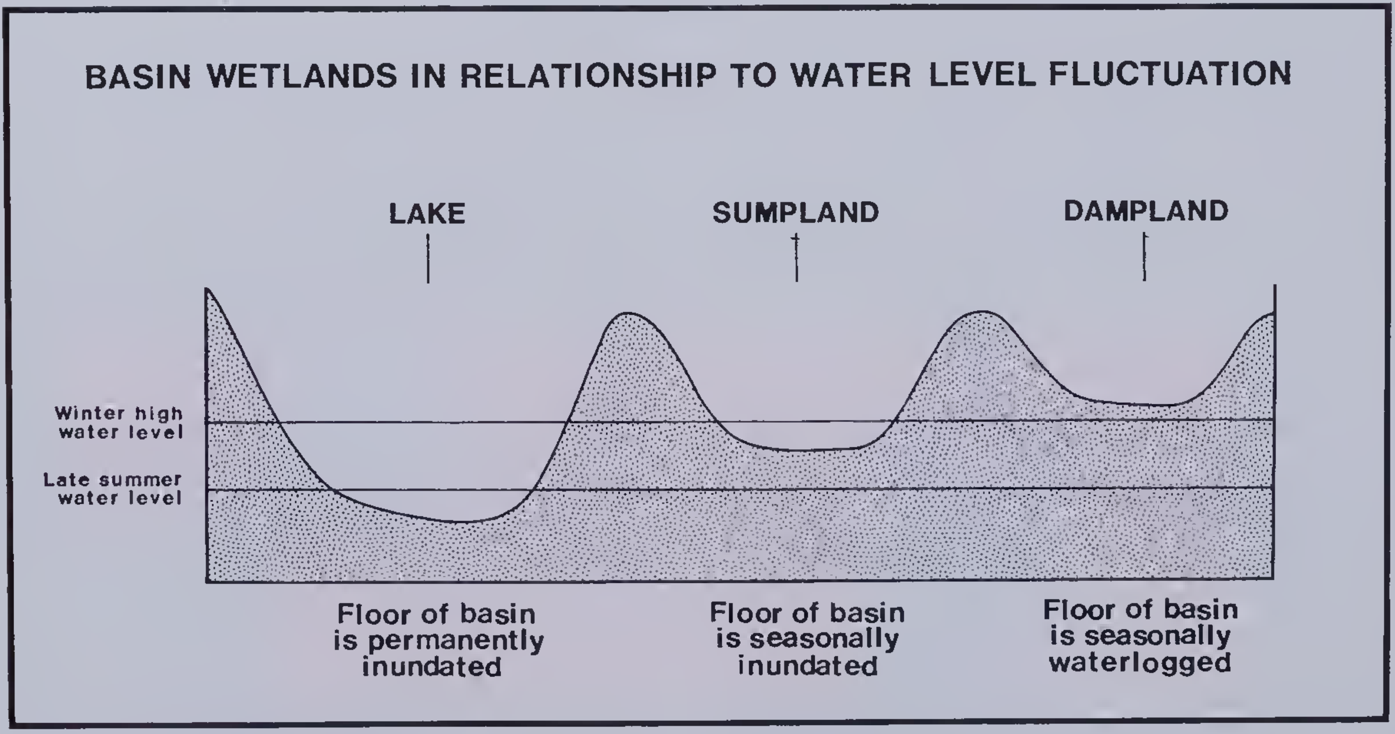

BASIN WETLANDS IN RELATIONSHIP TO WATER LEVEL FLUCTUATION
LAKE
SUMPLAND
DAMPLAND
Winter high water level
Late summer water level
Floor of basin is permanently inundated
Floor of basin is seasonally inundated
Floor of basin is seasonally waterlogged

Figure 5.—The development (based on permanence of water) of the 3 basin wetland categories, which in this example are related to landform position with respect to fluctuating water level.

and Williams 1973, Cowardin *et al.* 1979) of the terms limnetic and littoral to denote physical regions of a basin wetland is important in this classification. By denoting these separate zones, a wetland can be viewed in its entirety rather than as two or more separate wetlands e.g. the gradation from inundated surface to waterlogged soil may be seen as a continuous system. Thus the exposed marginal zone of a lake need not be viewed as a sumpland, but rather as a littoral zone.

Application of the proposed classification to wetlands of the Darling System

Several areas in different physiographic regions have been selected to indicate the practical use of the proposed classification and to display the range of wetlands occurring throughout the Darling System in their variability of geometry, size, and salinity. Figure 7 presents maps from four different geomorphic settings on the Swan Coastal Plain (McArthur and Bettenay 1960) and illustrates a range of wetland types in each selected area. Figure 8 presents hydrographs of selected wetlands from these areas to illustrate their hydrologic properties. The areas selected are:

1. Gnangara area
2. Ballajura area
3. Coogee area
4. Pt. Becher area

Table 4

Classification of some typical wetlands in the Darling system

Wetland	Primary Category	Full Classification *
Lake Joondalup	lake	macroscale, elongate fresh, stasohaline, lake.
Lake Bambun	lake	mesoscale, round subsaline stasohaline, lake.
Lake Coogee	lake	mesoscale, elongate hyposaline stasohaline, lake.
Lake Bibra	lake	macroscale, irregular fresh, poikilohaline, lake
Lake Cooloongup	lake	macroscale, ovoid hyposaline poikilohaline, lake.
Carine Swamp	sumpland	mesoscale, ovoid fresh, stasohaline. sumpland.
Lake Pinjar	sumpland	macroscale, ovoid fresh, stasohaline, sumpland.
Bollard Bullrush Swamp	sumpland	macroscale, round fresh, poikilohaline. sumpland.
Melaleuca Park	sumpland	microscale, ovoid fresh, poikilohaline, sumpland.
Stable Swamp	sumpland	microscale, linear fresh, stasohaline, sumpland.
Lake Bindiar	dampland	mesoscale, round fresh, stasohaline, dampland.
Lake Adams	dampland	macroscale, ovoid fresh, poikilohaline. dampland.
Yalbanberup Pool	river	mesoscale, sinuous hypersaline, poikilohaline, river.
Ellen Brook	creek	microscale, sinuous fresh, poikilohaline. creek.
Collie River tributory at Schotts	creek	microscale, straight fresh, stasohaline, creek

* Information for this classification based on 3 years of seasonal surveys.

The Gnangara area (Fig. 7) set in the Bassendean Dune system of McArthur and Bettenay (1960) is dominated by numerous unnamed microscale, round stasohaline, freshwater, sumplands and damplands. Lake Gnangara itself was an isolated macroscale, round, stasohaline freshwater lake; in recent years it has changed to being a sumpland. Snake Swamp is a mesoscale. ovoid, stasohaline, freshwater dampland. Badjerup Lake is a mesoscale, ovoid, stasohaline, freshwater sumpland.

In contrast, the Ballajura area set in the Bassendean Dune system and Pinjarra Plain alluvial system of McArthur and Bettenay (1960), contains wetlands that are mesoscale, straight and sinuous stasohaline creeks, a mesoscale, freshwater, poikilohaline river, mesoscale to macroscale floodplains which are poikilohaline, and microscale, freshwater, stasohaline sumplands and damplands.

The Lake Coogee area set in the Spearwood Dune System of McArthur and Bettenay (1960) has the following wetlands: Lake Coogee North is a mesoscale, elongate, poikilohaline, mesosaline sumpland; Lake Coogee South is a mesoscale elongate, stasohaline, hyposaline lake; the Henderson wetland complex is comprised of mesoscale, elongate, poikilohaline, freshwater sumplands; and Brownman's Swamp is a mesoscale ovoid, poikilohaline freshwater sumpland.

The Pt. Becher area, set in the Quindalup Dune system of McArthur and Bettenay 1960, is one in which microscale, ovoid, linear to irregular shaped, poikilohaline freshwater sumplands and damplands predominate.

Discussion

Wetlands are inherently complex ecological habitats but their analysis is simplified somewhat by a classification which brings into prominence the important wetland components of water and landform. Since there are only seven basic geomorphic wetland types, to which are added modifiers/descriptors of scale, plan geometry, and water properties, the classification enables one to distinguish a practicable number of wetland types. The basic wetland categories can then be ornamented/embellished to illustrate further variability with the addition of more detailed field information. But even without the more detailed studies a given wetland still can be readily classified into the primary categories with a minimum of field surveys. Thus the approach provided here has the advantages when additional detailed information becomes available of increasing the discrimination of individual wetlands from each other and from their surrounding areas; with less precise information available, categorisation at a broader level into a regional physiographic setting is also feasible.

The proposed classification also can provide useful mapping units since the various wetland types may be readily identified and mapped as categories. The regional differences and similarities between wetlands also would emerge more clearly and may be linked to other types of mapping parameters, e.g. contours, climate, geology. The "dry" wetland types in the Darling System, i.e. the damplands, which in the past were in some cases excluded, or included as wetlands on the basis of mixed criteria, can now be consistently identified as a category of wetland.

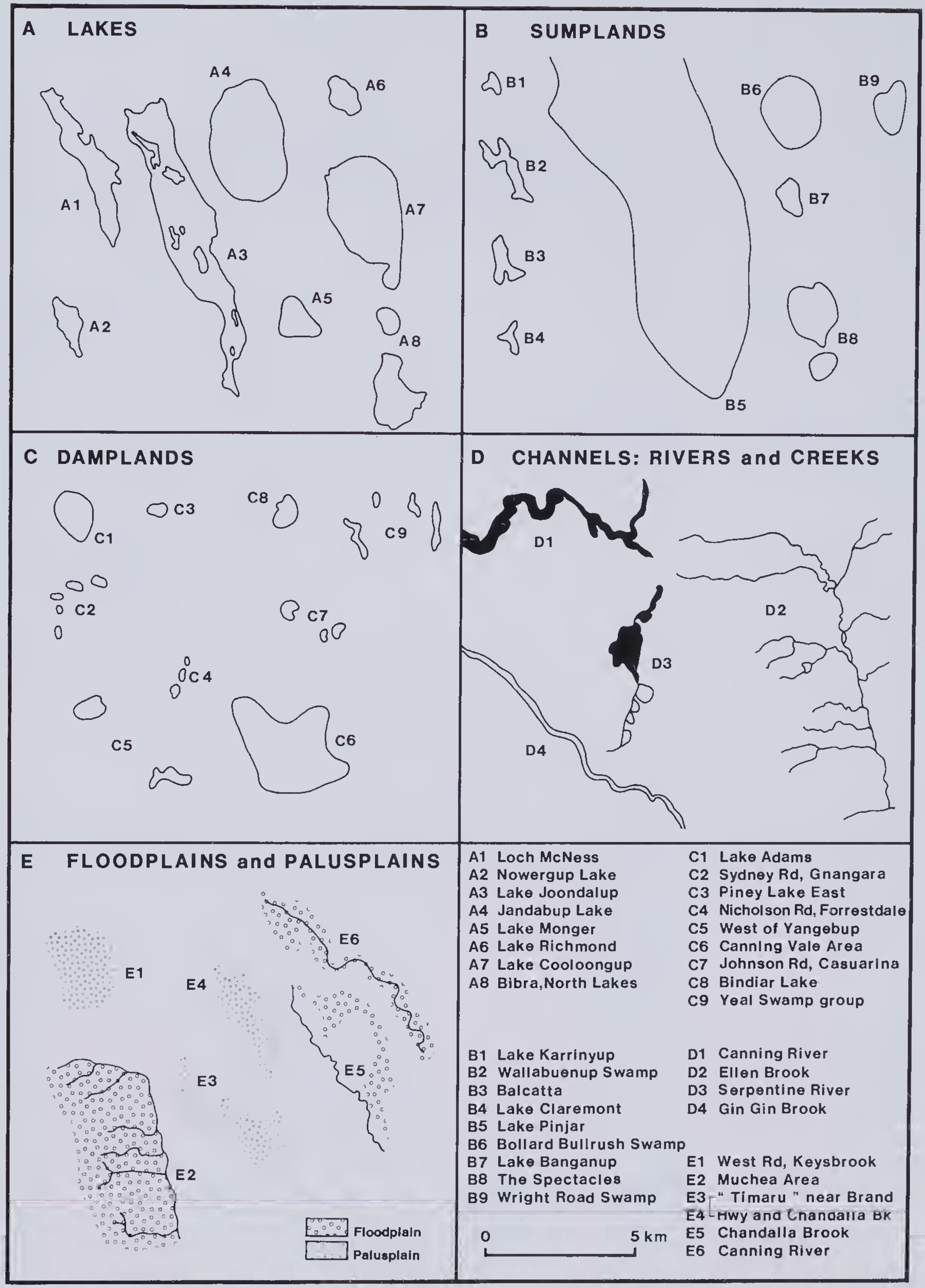


Figure 6.—Typical range of wetland categories in the Darling System.

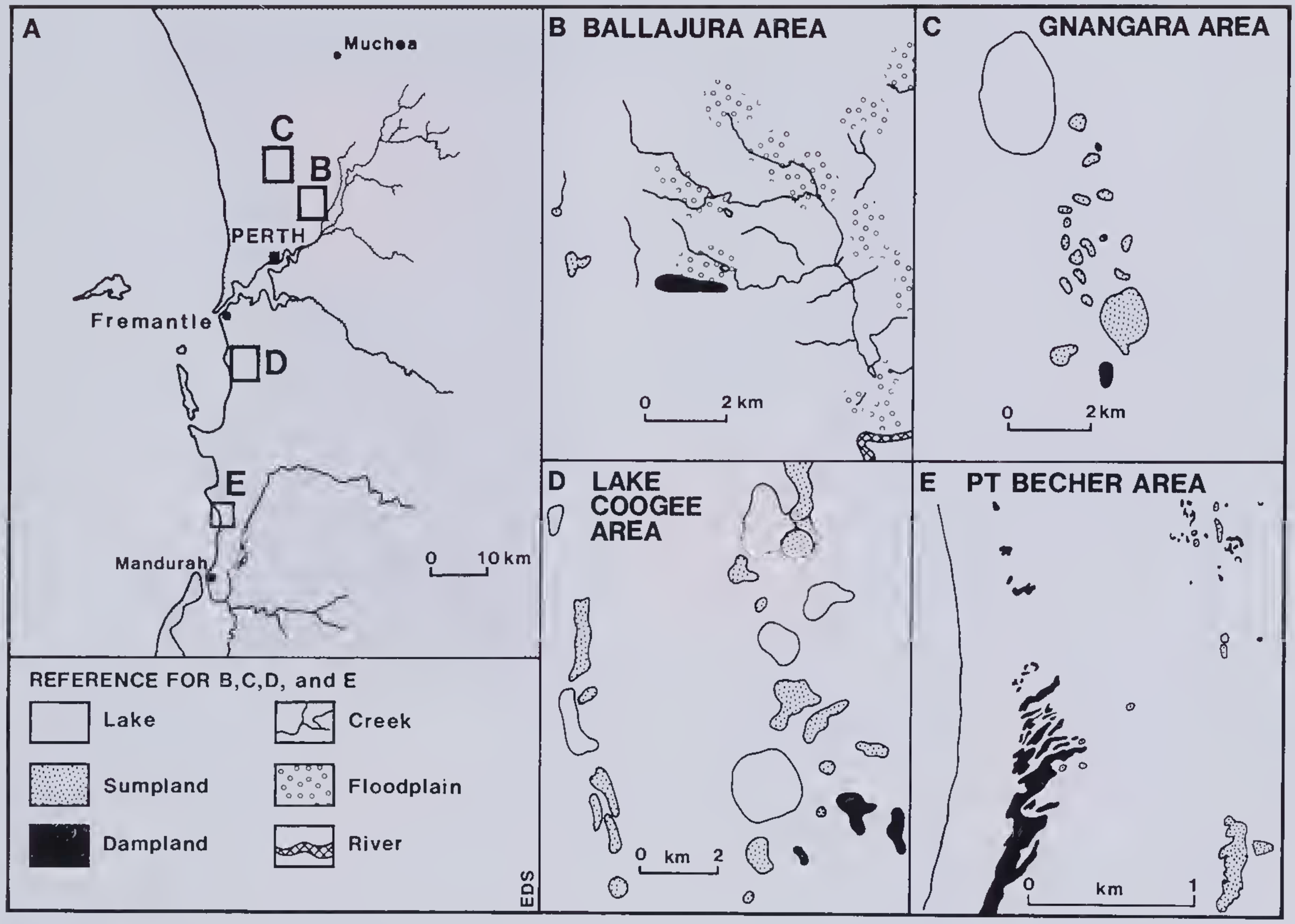


Figure 7.—Maps showing types and distribution of wetland categories for four selected areas.

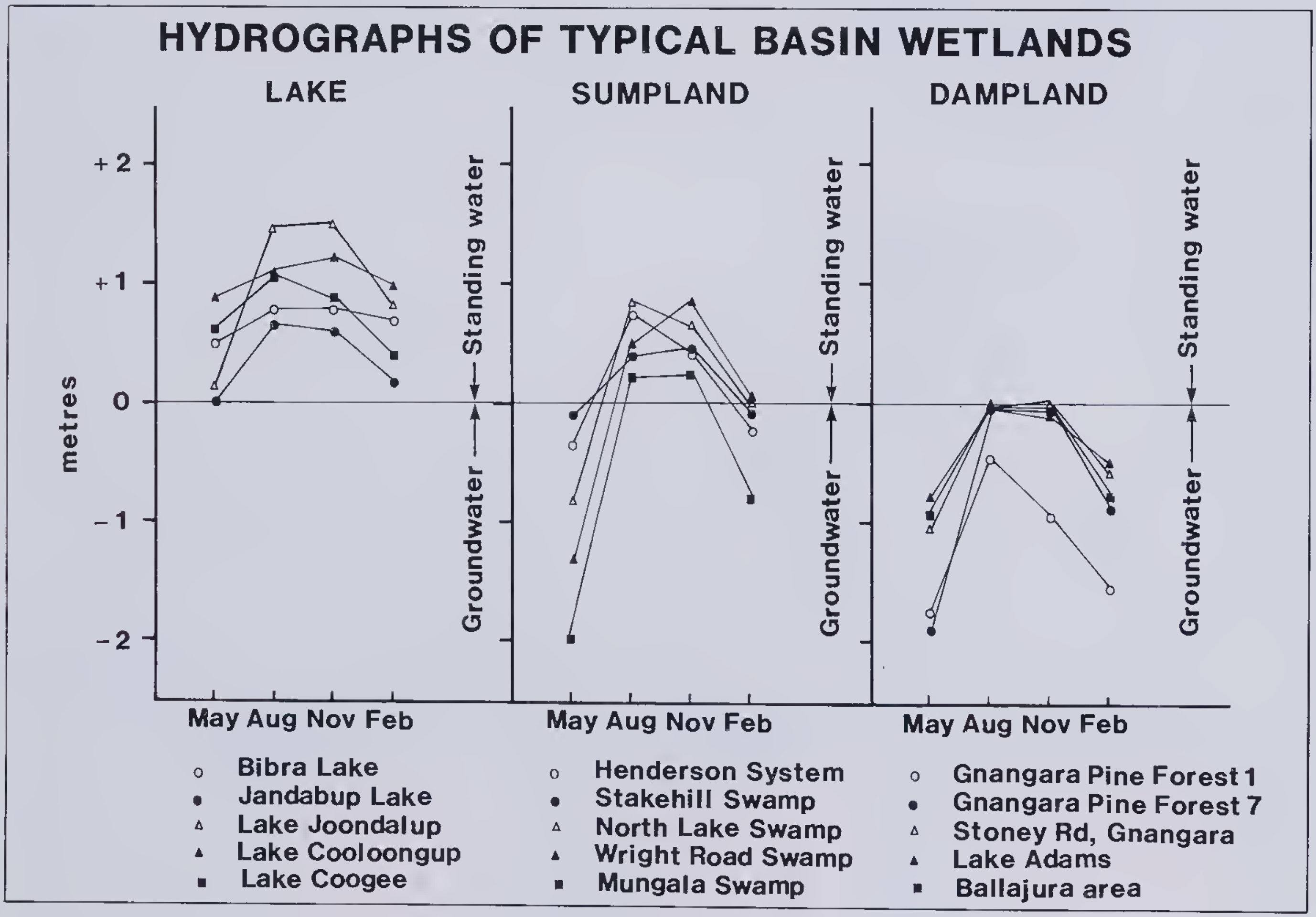


Figure 8.—Hydrographs of some typical basin wetlands on the Swan Coastal Plain.

Various wetland categories have a range of multifarious ecological functions and the proposed classification may parallel these functional delineations. For instance lakes. damplands and creeks are utilised by fauna in different ways because each of these wetlands are essentially different habitats as determined by the longevity and type of water input. For example some avifauna and reptiles use open water lakes for a specific range of purposes, whereas the vegetated sanctuary of many typical damplands may be utilised by mammals and other species of avifauna in a different capacity. Nutrient pathways and trophic inter-relationships also may be fundamentally distinct between these various primary wetland types. Botanists, zoologists, educationalist, recreational and land use planners may be able to make preliminary assessments of the diversity, dependence, complexity etc. of wetlands from the class to which it belongs. The advantage of the proposed classification also is that it can be used as a basis for any wetland study regardless of the ultimate discipline of the study (e.g. hydrology, stratigraphy, botany, zoology), and so circumvents the problem of a proliferation of nomenclature arising from specific applications/studies. Thus it provides a non-genetic framework upon which to base further detailed work.

Finally it is apparent that with the proposed classification a wetland can still be placed in its appropriate category even if it has been substantially altered by clearing of vegetation and disturbance of soils. As long as the mechanisms of water maintenance and basic geometry have not been destroyed then the inherent geomorphic wetland entity remains and can be identified and named.

Acknowledgements—The manuscript was critically reviewed by D. Glassford, I. LeProvost, V. Semeniuk and P. A. S. Wurm. Their help is gratefully acknowledged. Some of the research for this study was funded by VCSRG, Research and Educational Consultants and LeProvost, Semeniuk and Chalmer, Environmental Consultants.

References

Adam, P., Unwin, N., Weiner, P., Sim, I. and Winer, P. (1985).—*Coastal Wetlands of New South Wales.* Report for Department of Environment and Planning.

Allen, T. (1976).—Outline of the hydrogeology of the superficial formations on the Swan Coastal Plain *W.A. Geol. Surv. Ann. Rept.* **1975**: 31-42.

Allen, T. (1981).—Groundwater Resources of the Swan Coastal Plain, near Perth, Western Australia. In: *Groundwater Resources of the Swan Coastal Plain.* CSIRO. Proceedings of Symposium by CSIRO and Western Australian State Committee of Water Research Foundation.

Anderson, J. A. R. (1983).—The Tropical Peat Swamps of Western Malesia. In: Gore, A. J. P. (Ed.) *Ecosystems of the World. 4B. Mires: Swamp, Bog, Fen and Moor. Regional Studies.* Elsevier Scientific Publishing Co., p181-199.

Baird, A. M. (1984).—Observations on regeneration after fire in the Yule Brook Reserve near Perth. Western Australia. *J. Roy. Soc. W.A.*, **67**:1-13.

Bayly, J. A. E. and Williams, W. D. (1973).— *Inland Waters and Their Ecology.* Longman Cheshire.

Bates, R. L. and Jackson, J. A. (1980).—*Glossary of Geology.* American Geological Institute.

Bell, D. T., Loneragan, W. A. and Dodd, J. (1979).—Preliminary vegetation survey of Star Swamp and vicinity, Western Australia. *Herbarium Res. Notes* **Number 2**:1-21.

Bloom, A. L. (1978).—*Geomorphology. A Systematic Ananlysis of Late Cenozoic Landforms.* Prentice-Hall Inc., p197-278.

Briggs, S. V. (1981).—Freshwater Wetlands. In: R. H. Groves (Ed.). *Australian Vegetation.* Cambridge University Press, London, p335-360.

Campbell, E. O. (1983).—Mires of Australasia. In: Gore A. J. P. (Ed.) *Ecosystems of the World. 4B. Mires: Swamp, Bog, Fen and Moor. Regional Studies.* Elsevier Scientific Publishing Co., p153-180.

Cant, D. J. (1982)-Fluvial Facies Models and their Application. In: Scholle. P. A. and Spearing, D. (Eds.) *Sandstone Depositional Environments. Am. Assoc. Petrol. Geol.*, **Mem 31**: 115-121.

Chorley, R. J. (1969).—The Drainage Basin as the Fundamental Geomorphic Unit, In: Chorley, R. J., (Ed.) *Introduction to Fluvial Processes.* Methuen & Co. Ltd, p30-51.

Clarke, E. de C., Prider, R. T., Teichert, C. (1971).—*Elements of Geology for Australian Students.* University of W.A. Press.

Congdon, R. A. and McComb, A. J. (1976).—The nutrients and plants of Lake Joondalup, a mildly entrophic lake experiencing large seasonal changes in volume. *Roy. Soc. W.A.*, **59**: 14-23.

Cowardin, L. M., Carter, V., Golet, F. C. and LaRoe, E. T. (1979).—*Classification of wetlands and deepwater habitats of the United Stated.* U.S. Dept. of the Interior: Fish & Wildlife Service Dec.

Cowling, S. L. (1977).—Classification of the wetland habitats of waterbirds. *Aust. Mar. Sci. Bull.*, **58.**

Dahl, E. (1956).—Ecological salinity boundaries in poikilohaline waters. Oikos, 7: 1-21.

Davis, S. N. and DeWiest. R. J. (1966).—*Hydrogeology*, John Wiley & Sons Inc., p118.

Denny, P. (Ed.) (1985).—*The Ecology and Management of African wetland vegetation.* W. Junk Publishers.

Department of Conservation and Environment (1980).—Wetlands Guidelines for protection and management. *Dept. Conservation & Environment* **Bulletin No. 79.**

Drever, J. I. (1982).—*The Geochemistry of Natural Water.* Prentice-Hall. Inc.

Evans. G. A. and Sherlock, N. V. (1950).—Butler's Swamp Claremont, *Western Australian Naturalist.*,**2**: 152.

Fairbridge, R. W. (Ed.) (1968).—*The Encyclopedia of Geomorphology. Vol. III.* Dowden, Hutchinson & Ross Inc.

Leeder, M. R. (1982).—*Sedimentology Process & Product.* Allen & Unwin.

Gilluly. J., Waters, A. C. and Woodford, A. O. (1951).—*Principles of Geology.* Freeman & Co., p224-231.

Golet, F. C. and Larson, J. S. (1974).—Classification of Freshwater Wetlands in the Glaciated Northeast. Resource Publication 116. US. Fish and Wildlife Service Washington, D.C.

Goodrick, G. M. (1970).—A Survey of Wetlands of coastal New South Wales, *CSIRO Division of Wildlife Research Technical Memorandum.* **No. 5.**

Gore, A. J. P. (1983).—Introduction, In: Gore A. J. P. (Ed.) *Ecosystems of the World. 4A. Mires: Swamp, Bog, Fen, and Moor. General Studies.* Elsevier Scientific Publishing Co., p1-34.

Gorham, E. (1953).—Some Early Ideas Concerning the Nature, Origin and Development of Peat Lands. *Jour. Ecology.*, **41**: 257-273.

Gorham, E. (1957).—The Development of Peatlands. *Quart. Review Biology.*, **32**: 147-164.

Hakanson, L. and Jansson, M. (1983).—*Principles of Lake Sedimentology.* Springer-Verlag, p5-17.

Hammer, U. T., (1986).—*Saline Lake Ecosystems of the World.* Dr. W. Junk Publishers.

Hammer, U. T. Shamess, J., and Haynes, R. C. (1983).—The distribution and abundance of algae in saline lakes of Saskatchewan, Canada. In: U. T. Hammer (ed.) *Saline Lakes* Proc. 2nd Int. Symp Athalassic Inland Saline Lakes, Dev. Hydrobiol 16 Junk, The Hague, p1-26.

Hill, J. R. Jr. (1978).—Corps of Engineers efforts related to Wetland Protection. In: Montanari, J. H. and Kusler, J. A. (Ed.) *Proceedings of the National Wetlands Protection Symposium*, 1977. Reston, Va. U.S. Dept of the Interior Fish and Wildlife Service FWS/OBS-78/79. Washington D.C.

Hofstetter, R. H. (1983).—Wetlands in the United States, In: Gore, A. J. P. (Ed.) *Ecosystems of the World. 4B. Mires; Swamp, Bog, Fen and Moor. Regional Studies.* Elsevier Scientific Publishing Co., p201-244.

Holmes, A. (1944).—*Principles of Physical Geology.* Nelson. p437-440 and p671-675.

Howard Williams, C. and Gaudet, J. J. (1985).—The Structure and functioning of African Swamps. In: Denny, P. (Ed.) *The Ecology & Management of African Wetland Vegetation.* W. Junk Publishers, p153-176.

Hutchinson, G. E. (1957).—*A Treatise on Limnology. Vol. I.* Wiley & Sons.

Ivanov, K. E. (1981).—*Water Movement in Mirelands.* Academy Press.

Jacobs, S. W. L. (1983).—Vegetation. In: Haigh, C. (Ed.), *Wetlands* in N.S.W. Parks and Wildlife, p14-19.

Junk, W. J. (1983).—Ecology of Swamps on the Middle Amazon. In: Gore, A. J. P. (Ed.) *Ecosystems of the World. 4B. Mires: Swamp, Bog, Fen and Moor. Regional Studies.* Elsevier Scientific Publishing Co., p269-294.

Kulczynski, F. (1949).—Peat bogs of Polesie, *Mem. Acad. Sci. Cracovie.*, **Ser. B**: 12356.

Leopold, L. B., Wolman, M. G. and Miller, J. P. (1964).—*Fluvial Processes in Geomorphology.* W. H. Freeman & Co., San Francisco.

Logan, B. W., Read, J. F., Hagan, G. M., Hoffman, P., Brown, R. G., Woods, P. J. and Gebelein, C. D. (1974).—Evolution and Diagenesis of Quaternary Carbonate Sequences, Shark Bay, Western Australia. *Am. Assoc. Petrol. Geol.*, **Mem. 22.**

McArthur, W. M. and Bettenay, E. (1960).—The Development and Distribution of the Soils of the Swan Coastal Plain Western Australia. *CSIRO Soil Publication* **No. 16.**

Martin, A. C., Hotkiss, N., Uhler, F. M. and Bourn, W. S. (1953).—Classification of Wetlands of the United States. *U.S. Fish Wildl. Service. Spec. Sci Rep. Wildl.* **No. 20.**

McComb, J. A. and McComb, A. J. (1967).—A Preliminary Account of the Vegetation of Loch McNess, a swamp and fen formation in Western Australia. *Roy. Soc. W.A.*, **50**: 105-112.

Miall, A. D. (1977).—A Review of the braided river depositional Environment: *Earth Sci. Rev.*, **13**: 1-62.

Mill, H. R. (1900-1910).—In: Sir Dudley Stamp (Ed.) 1966. *A Glossary of Geographical Terms.*

Monkhouse, F. J. (1965).—*A Dictionary of Geography.* E. Arnold and Chicago Aldine.

Moore, P. D. and Bellamy, D. J. (1974).—*Peatlands.* London, Elek Science, p9-183.

Moore, W. G. (1949).—*A Dictionary of Geography.* Penguin Books. Harmondsworth, Middlesex.

Morisawa, M. (1968).—*Streams: Their dynamics and morphology.* New York, McGraw-Hill Book Co.

Muir, B. G. (1983).—Drainage, Swamp Structure and Vegetation Succession at Melaleuca Pk, Northern Swan Coastal Plain. *Herbarium Research Notes.* **No. 9**: 27-39.

Paijmans, K., Galloway, R. W., Faith, D. P., Fleming, P. M., Haantjens, H. A., Heyligers, P. C., Kalma, J. D. and Loffler, E. (1985).—Aspects of Australian Wetlands. *CSIRO Aust. Div. Water Land Resources Technical Paper.* **No. 44**: 1-71.

Pen, L. J. (1983).—Peripheral Vegetation of the Swan and Canning Estuaries 1981. *Dept. of Conservation and Environment*, **Bull. 113.**

Pisano, E. (1983).—The Magellanic Tundra Complex In: Gore, A. J. P. (Ed.) *Ecosystems of the World. 4B. Mires, Swamp, Bog, Fen and Moor. Regional Studies.* Elsevier Scientific Publishing Co., p295-330.

Reeves, C. C. Jr. (1968).—*Introduction to Palaeolimnology.* Elsevier.

Reineck, H. E. and Singh, I. B. (1973).—*Depositional Sedimentary Environments.* Springer-Verlag.

Riggert, T. L. (1964-1966).—Wetlands of Western Australia Department of Fisheries and Fauna West. Aust.

Ruttner, F. (1953).—*Fundamentals of Limnology.* University of Toronto Press.

Ruuhijarvi, R. (1983).—The Finnish Mire Types and Their Regional Distribution. In: Gore, A. J. P. (Ed.) *Ecosystems of the World. 4B. Mires; Swamp, Bog, Fen and Moor. Regional Studies.* Elsevier Scientific Publishing Co., p47-68.

Schumm, S. A. (1977).—*The Fluvial System.* John Wiley & Sons.

Seddon, G. (1972).—*A Sense of Place.* University of WA Press.

Semeniuk, V. (1986).—Terminology for geomorphic units and habitats along the tropical coast of Western Australia. *J. Roy. Soc. W.A.* **68**:

Shipley, J. T. (1982).—*Dictionary of Word Origins.* Littlefield, Adams & Co.

Sjors, H. (1983).—Mires of Sweden. In: Gore, A. J. P. (Ed.) *Ecosystems of the World. 4B. Mires; Swamp, Bog, Fen and Moor. Regional Studies.* Elsevier Scientific Publishing Co., p69.94.

Smith, D. G. (1983).—Anastomosed fluvial deposits: modern examples from Western Canada. In: J. D. Collinson and J. Lewin (Ed.) *Modern and Ancient Fluvial Systems.* Special Publication Number 6 of the International Association of Sedimentologists. Blackwell Scientific Publications, p155-168.

Speck, N. H. and Baird, A. M. (1984).—Vegetation of Yule Brook Reserve near Perth, Western Australia. *J. Roy. Soc. W.A.*, **66**: 147-162.

Strahler, A. N. and Strahler, A. H. (1978).—*Modern Physical Geography.* John Wiley & Sons.

Swayne, B. (1956).—A Concise Glossary of Geographic Terms. In: Sir D. Stamp (Ed.) (1966) *A Glossary of Geographic Terms.*

Tansley, A. G. (1939).—*The British Islands and Their Vegetation.* Cambridge University Press, Cambridge.

Tingay, A. and Tingay, S. R. (1976).—The Wetland of System Six. *Dept. Conservation & Environ.* **Bull. 28.**

Trowbridge, A. C. (Ed.) (1962).—*Dictionary of Geological Terms.* American Geological Institute, Washington D.C.

Twidale, C. R. (1968).—*Geomorphology.* Nelson, p148-203.

UNESCO (1971).—Article 1, part 1, Convention on wetlands of international significance especially as waterfowl hibitats. Published in Australia, 1976, for Department of Foreign Affairs by Australian Government Publishing Service, Treaty Series 1975, No. 48.

Watson, L. E. and Bell, D. T. (1981).—The Ecology of Star Swamp and surrounding bushlands, North Beach, Western Australia. *J. Roy. Soc. W.A.*, **63**: 103-117.

Wetlands Advisory Committee (1977)—The Status of Wetland Reserves in System 6. Report of the Wetlands Advisory Committee to the Environmental Protection Authority.

Whittow, J. B. (1984).—*Penguin Dictionary of Physical Geography.* Penguin Books Hammondsworth, Middlesex.

Wetzel, R. G. (1983).—*Limnology.* Saunders College Publishing.

Zoltai, S. C. and Pollett, F. C. (1983).—Wetlands in Canada: Their Classification, Distribution and Use. In: Gore, A. J. P. (Ed.) *Ecosystems of the World. 4B. Mires; Swamp, Bog, Fen and Moor. Regional Studies.* Elsevier Scientific Publishing Co., p245-268.